MMIC Amplifier Based Receivers for Earth Remote Sensing

Douglas E. Dawson, Todd Gaier, and Sander Weinreb
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099

Matt Morgan
California Institute of Technology
1200 E. California Blvd.
Pasadena, CA 91125

Abstract—**We have developed amplifier based receivers using Indium Phosphide high electron mobility transistor (HEMT) monolithic microwave integrated circuit (MMIC) technology. These compact receivers are designed with atmospheric temperature and humidity sounding requirements in mind, operating at 100-140 GHz around the 118 GHz oxygen line and at 170-200 GHz near the 183 GHz water line. We have also developed a compact MMIC based filter bank designed to provide coarse spectroscopic capability for these receivers. The technology development will be presented as well as promising future developments in this area.**

I. Introduction

Several chips and modules have been developed for compact (< 0.5 kg), low power (<0.4W), calibrated radiometric sensors operating in the 100-140 and 170-210 GHz ranges. These chips, developed utilizing InP transistor monolithic microwave integrated circuits (MMICs), have enabled a factor of 100 reduction in volume as compared to the sensors presently used in programs such as AMSU and MLS.

Millimeter-wave spectrometers have been used to monitor atmospheric temperature, pressure and humidity as well as upper atmospheric chemical composition [1][2], key data products for monitoring how the Earth system responds to natural and induced changes; particularly the effects of regional pollution on the global atmosphere, and the effects of global chemical changes on regional air quality. Current instruments, which use older millimeter-wave technologies, include UARS-MLS and AMSU-A&B. Future versions of these missions will be revolutionized by reduced size, mass, cost and power required for MMIC technology at millimeter wavelengths.

Atmospheric temperature, pressure and humidity can be measured by monitoring emission at frequencies on and near molecular lines (e.g. O_2 at 59 or 118 GHz and H_2O at 22 or 183 GHz). Observation of O_2 and H_2O at higher frequencies results in much smaller antennas for a given resolution. In addition, the 100-140 GHz range allows a measurement of carbon dioxide abundance from its 115 GHz line, mid- and lower-tropospheric water vapor from continuum emission, and stratospheric ozone from several lines in this range. Additional data products in the 170-210 GHz band are, stratospheric ozone, and the abundance of ClO (the predominant form of reactive chlorine that destroys ozone), N_2O, HNO_3, and volcanically-ejected SO_2.

A specific application of the these sensors is for a Scanning Microwave Limb Sounder (SMLS), which has been proposed as a follow on to UARS MLS and EOS MLS. ***A main theme of our work has been to develop and perform a laboratory demonstration of one receiver element of the SMLS instrument. This receiver also has a wide range of other applications where a compact, low-cost single radiometer for temperature and humidity is needed.*** We have also developed a compact MMIC based filter bank designed to provide coarse spectroscopic capability for these receivers.

II. MMIC Receivers

A. Receiver Design

The 100-140GHz receiver schematic is shown in Fig. 1, and is very similar to the 170-210 GHz design, except that the higher frequency receiver uses a 2nd harmonic mixer. A picture of the inside of a receiver assembly is shown in Fig.2. Both receivers consist of 5 MMIC chips, all approximately 2x0.7 mm in size. The total DC power consumption for these modules is approximately 200mW.

Each MMIC has key functionality in the receiver chain. The low noise amplifiers (LNA's) provides enough front end gain and low enough noise figure to provide good noise temperature over the band without large impacts from the elements later in the chain. The MMIC mixer

Table I: MMIC Summary

170-210GHz MMICs

Function	Type	Foundry	Status
LNA	ALP114*	TRW	Tested, B (*TRW design*)[3]
	200LN1	TRW	Tested, B
	200LN2	HRL	Tested, B ♠
	200LN3	HRL	In Fabrication
	200LN4	HRL	Tested, D ♠
	190LN1	Lockheed	Tested, C
Mixer	200MIX1	UMS	Tested, B
IF Amplifier	WBA7	HRL	Tested, A
	WBA7T	TRW	Tested, A ♠
LO Amplifier	70LN3	HRL	Tested, A ♠

100-140GHz MMICs

Function	Type	Foundry	Status
LNA	120LN1	TRW	Tested, B
	120LN1	Lockheed	Tested, B ♠
	120LN2	TRW	F, Mask Error
	120LN2	TRW	F, Fab Error
	120LN3	TRW	Tested, C
	120LN4	HRL	Tested, D
	120LN5	TRW	Tested, F
	120LN6	TRW	Tested, C
	120LN7	HRL	In Fabrication
	120LN8B	TRW	Tested, A
	118LN3	HRL	Tested, B ♠
Mixer	120MIX1	UMS	Tested, C
	120MIX2	TRW	Tested B ♠
IF Amplifier	WBA7	HRL	Tested, A
	WBA7T	TRW	Tested, A ♠
LO Amplifier	70LN3	HRL	Tested, A ♠

A-Meets all Requirements, B-Needs Minor Improvement, C-Functional, D-Not Usable, F- Not Functional

♠ **Denotes MMIC used in first prototype modules**

*ALP114 Designed independently by TRW [1]

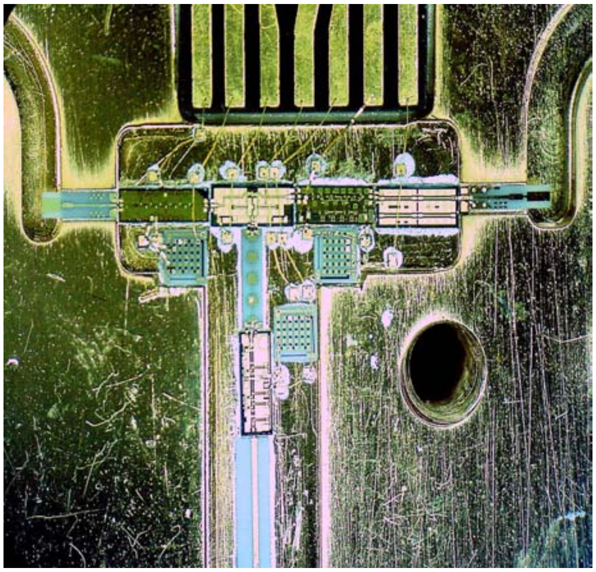

Fig.2 100-140 GHz Receiver Assembly

has reasonably good conversion loss and is easier to integrate into the chain than a typical waveguide mixer assembly. The local oscillator (LO) amplifier provides enough output power (+7dBm) so that the LO distribution system outside of the receiver can be low power, thus significantly simplifying array systems that would employ many receivers. The intermediate frequency (IF) amplifier provides more than 20dB of gain at the exceptionally broad IF band necessary to cover all appropriate RF frequencies.

The key to the dramatic size and weight reduction as compared to earlier systems is having all of the key components realized in MMIC technology, allowing close integration of very small chips shown in Fig.2. A summary of all the MMIC chips produced by the program is listed in Table I.

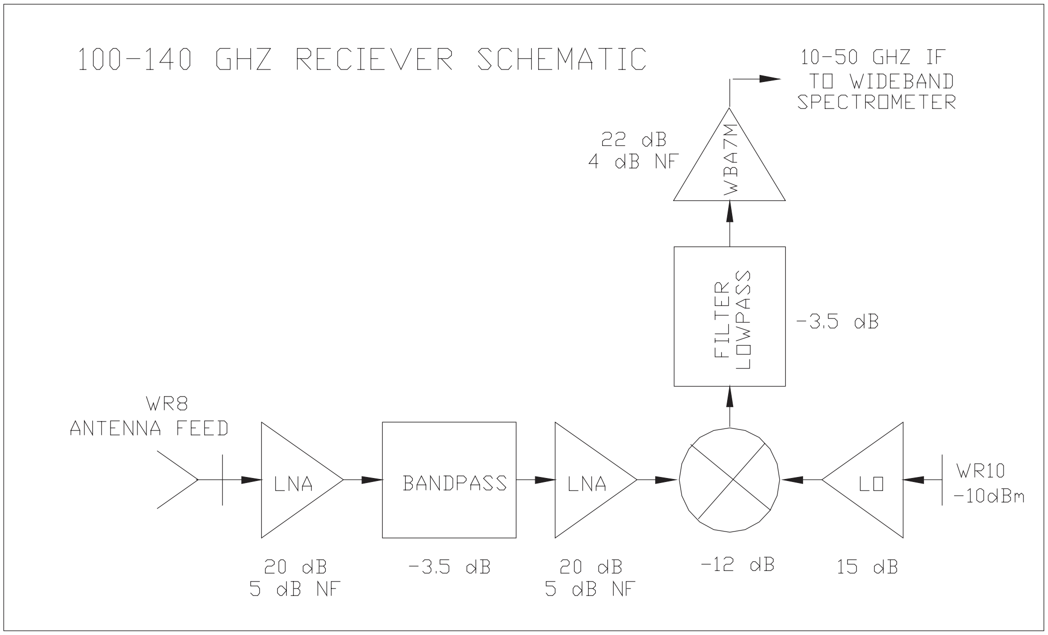

Fig.1 MMIC Receiver Schematic

B. MMIC LNA's

By far the most challenging designs were the LNA's, and the best LNA's were developed recently and are still under test. The key to realizing these designs at such high frequency and bandwidth is a precise model for the HEMT in the frequencies of interest. We have very good candidates LNA's in both bands.

The best 100-140GHz LNA is 120LN8B. A drawing of the chip layout is shown below in Fig.3, and the chip gain is shown in Fig.4. Two of these chips will be packaged together with a microstrip filter and optimized for ambient noise temperature. That module will then be connected with the previously tested module, containing the rest of the MMICs described in section I, to complete a receiver.

The 200GHz frequency range is the forefront of MMIC technology, and although most of our bandwidth requirements have been meet, it is a difficult and very challenging range. The best 170-210 GHz LNA was developed independently by TRW [3], and two chips and a filter have been packaged and tested for gain at JPL. The results are in Fig.5. Ambient noise temperature measurements and integration with the remaining part of the receiver will follow. TRW has measured better than 6 dB noise figure [3] at the module level from 175-195GHz for this chip design.

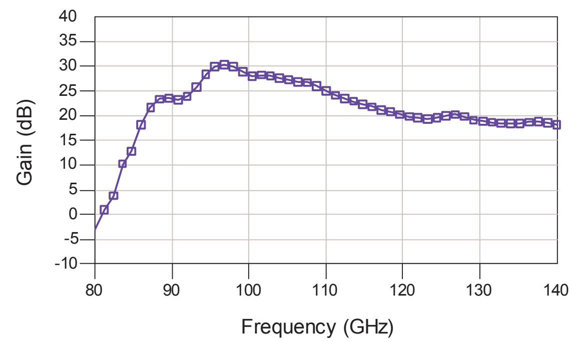

Fig.4: 120LN8B Gain

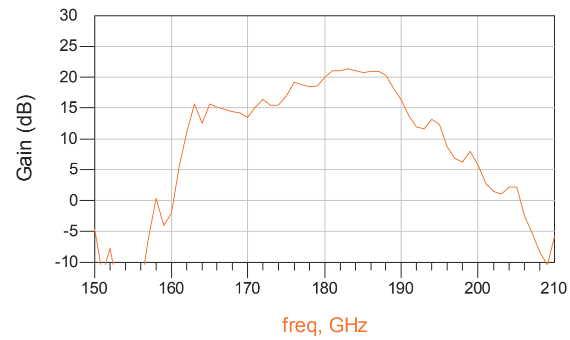

Fig.5 : ALP114 Chain with filter

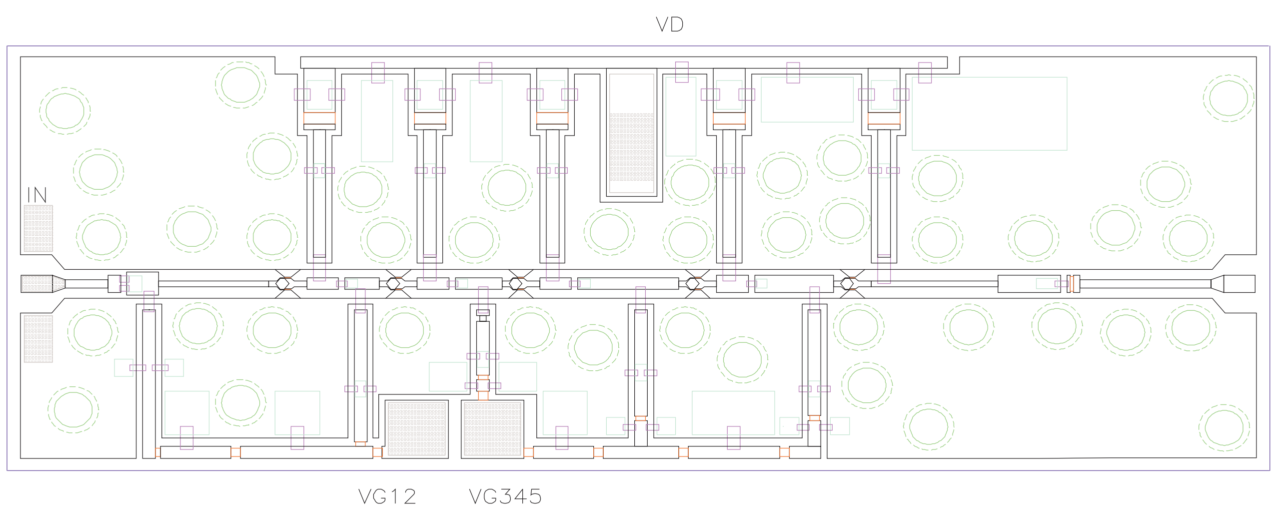

Fig.3: MMIC LNA 120LN8B

III. Wide Band Filter Bank Spectrometer

In addition to the receivers themselves, we have also developed a wide band, compact spectrometer to process the wide 10-50GHz IF signal produced by the receivers. The schematic for this package is shown in Fig.6. The total package is less than 4 inches square, and .34 inches thick. It is primarily enabled by the wide band IF amplifier WBA7M, which combines good compression, 25dB of gain from 10-50GHz, and small size and power consumption. The RF chain consists of several WBAT7Ms connected with power dividing and multiplexing Alumina microstrip circuitry. This chain takes the 10-50GHz input and produces 16 1GHz wide outputs which are feed into diode detectors. The voltage produced by the diodes is the sent to an op-amp, and then into an analogue multiplexer, which selects and sends the detected signals to the output pins. This module is currently under test.

IV. Future Work

A. Receivers

Both receivers, once fully integrated with their front end LNA's, will be tested for ambient noise temperature.

B. Spectrometer

The spectrometer will be completely tested once integrated, and connected to the 100-140GHz receiver for an overall test.

C. Future LNA Work

The dual LNA packages will also be individually tested for gain and noise temperature at 20K, providing the first cryogenic noise test done in these bands. We expect nearly a factor of 10 decrease in noise temperature when cooled.

We also plan to push the operating frequency of the MMIC LNA's to 250GHz. As described earlier, the 200GHz range is already difficult, but we believe that some process changes will allow the LNA's to perform up to 250 GHz. These LNA's could be cooled, or run in an array to provide excellent measurement capability for the 200-250GHz range, which is critical for tropospheric chemistry [4]. This work has been proposed to The Earth Science and Technology Office through their Advanced Component Technology program.

V. Acknowledgment

The author would like to thank: Mike Delaney and Adele Schmitz of HRL; Ron Grunbacker, Rohit Raja, Roger Tsai, Linda Florero, and Nyla LaGarde of TRW; all for their support in MMIC development. Also Gene Fisher and Mary Wells for critical and precise assembly work.

This work is supported by NASA's Earth Science Technology Office Instrument Incubator Program, and portions of this work were supported by NASA's Breakthrough Sensor and Instrument Component Technology Program.

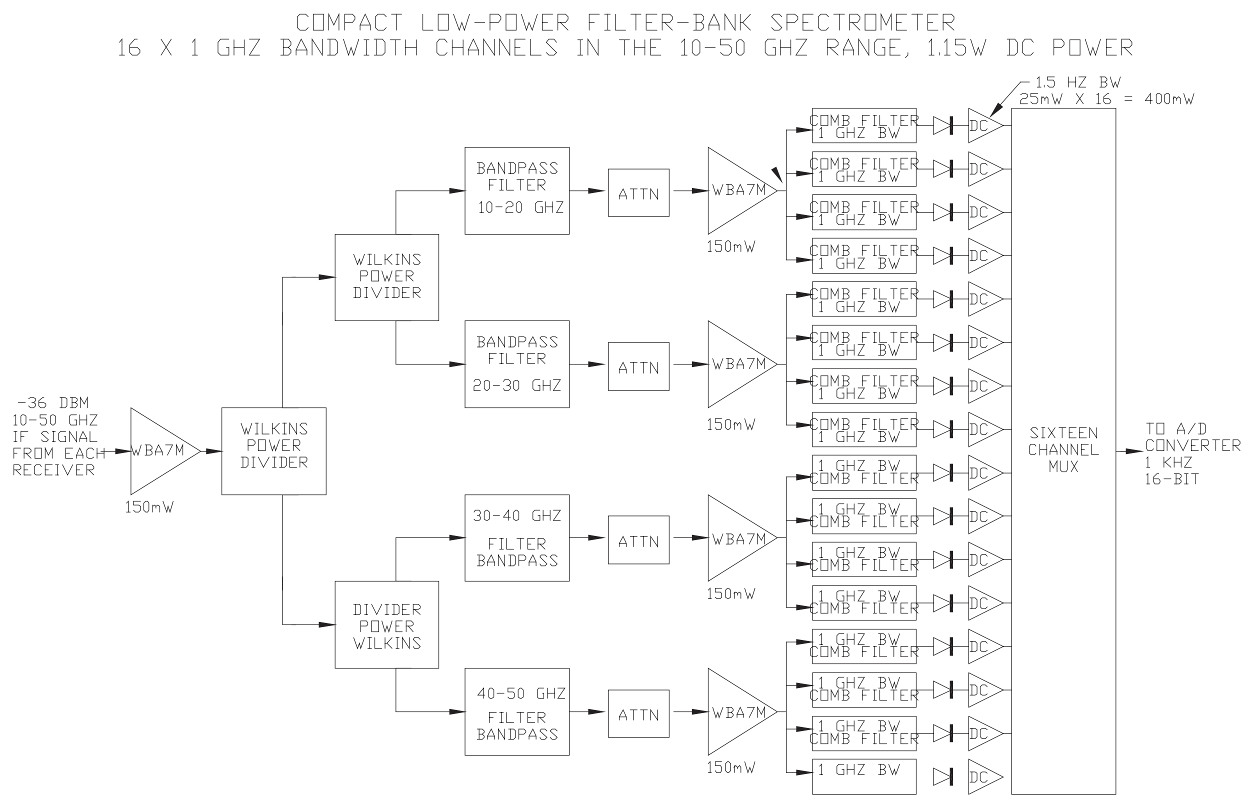

Fig.6

REFERENCES

[1] M.A. Janssen, editor, *Atmospheric Remote Sensing by Microwave Radiometry*, John Wiley, 1993.

[2] J.W. Waters, "Observations for Chemistry (Remote Sensing): Microwave (Ground, Aircraft, Balloon, Satellite), in *Encyclopedia of Atmospheric Sciences*, Academic Press, in press. (manuscript available at http://mls.jpl.nasa.gov.)

[3] Raja, R.; Nishimoto, M.; Osgood, B.; Barsky, M.; Sholley, M.; Quon, R.; Barber, G.; Liu, P.; Lai, R.; Hinte, F.; Haviland, G.; Vacek, B., "A 183 GHz Low Noise Amplifier Module with 5.5 dB Noise Figure for the Conical-Scanning Microwave Imager Sounder (CMIS) program," Microwave Symposium Digest, 2001 IEEE MTT-S International, Volume: 3, May 2001 Page(s): 1955 -1958

[4] J.W. Waters et al., "Technology for an Advanced Microwave Sensor fro Atmospheric Chemistry," submitted to 2002 EST Conference.